A Consortium for Ocean Circulation and Climate Estimation – JPL

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LONG-TERM GOALS

The project's goal is to advance ocean data assimilation into a quasi-operational tool for studying ocean circulation. Observing the complete state of the ocean is difficult owing to its turbulent nature and sparse and limited measurements. This project will establish a routine description of the global ocean by optimally combining available observations using a general circulation model, in order to assess, monitor, and understand ocean circulation. The effort further aims to demonstrate the practical utility of ocean observing systems by developing applications of such syntheses.

OBJECTIVES

The project's central technical goal is to establish a complete global ocean state estimation over the 16-plus year period from 1985 to present at 1/4º resolution with complete error descriptions, combining all available large-scale data sets with a state-of-the-art general circulation model. Of particular interest is understanding processes underlying the recent 1997-99 El Nino/La Nina event and the possible shift in the Pacific Decadal Oscillation in 1999. Tools necessary for such synthesis will be advanced, including improvements in models and assimilation techniques, with an emphasis on devising practical solutions in marshaling diverse data sets and large numerical models on a routine basis. The effort will exploit existing and ongoing oceanographic experiments (e.g., WOCE) and satellite missions (e.g.,

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14. ABSTRACT
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15. SUBJECT TERMS

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TOPEX/POSEIDON) and will support planned experiments including the Climate Variability and Predictability Program (CLIVAR) and the Global Ocean Data Assimilation Experiment (GODAE).

APPROACH

Advanced data assimilation schemes and state-of-the-art numerical ocean general circulation models are employed to analyze global oceanographic observations. The model is based on a new parallel version of the MIT ocean general circulation model (Marshall et al., 1997.) The model's parallelization allows exploiting massively parallel supercomputers to simulate the ocean at much higher spatial resolution than otherwise possible. The present model extends from 80°S to 80°N with a fairly high resolution (1° by 0.3° within the tropics, with 10m near surface layers) and employs advanced mixing schemes to best simulate diabatic processes. The assimilations employ both an advanced Kalman filter and smoother (KFS) and the adjoint method. Results of the two approaches are compared to optimize the assimilation and to transition the calculation into a routine analysis. I.Fukumori and T.Lee are technical leads in the KFS and adjoint assimilations, respectively. Assimilation of ancillary data is being investigated by D.Menemenlis. L.Fu is responsible for programmatic oversight, and V.Zlotnicki is investigating high-frequency ocean bottom pressure variations. This project is part of a larger consortium formed under the National Oceanographic Partnership Program (NOPP). The synergistic efforts of the consortium elements are described below ("RELATED PROJECTS.")

WORK COMPLETED

The adjoint of the parallel MIT ocean circulation model has been developed using an automatic differentiation tool (Giering and Kaminski, 1998) allowing adjoint assimilation on a massively parallel supercomputer. In addition, a novel assimilation method termed the Partitioned Kalman filter and smoother (PKFS) has been devised (Fukumori, 2001). The approach partitions model uncertainties into a sum of independent elements that are solved separately from one another with significant computational savings. Development of the parallel model adjoint and PKFS enables data assimilation using much larger and, consequently, higher resolution models than hitherto possible. The methods have been applied with the model described above, to assimilate satellite altimetry measurements and other ancillary observations covering the period from 1993 to 2000. These results constitute one of the largest data assimilated model estimates of the ocean to date. A data server has been established (Live Access Server at http://www.ecco-group.org) that makes these results available to the general oceanographic community. Analyses and additional information are provided at the JPL-ECCO server, http://ecco.jpl.nasa.gov/odap/html/ .

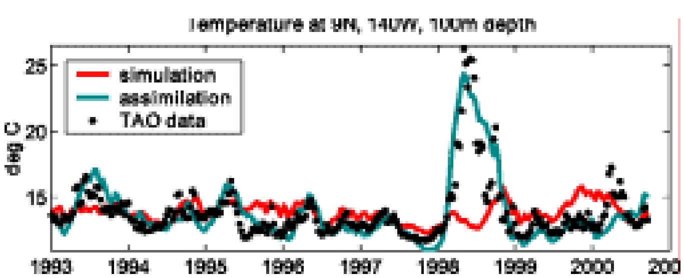

Figure 1: Temperature Time Series at 9ºN 140ºW 100m Depth. [Sea level assimilation corrects the model's underestimation of the latitudinal extent of warming associated with the 1998-99 El Nino.]

RESULTS

Global ocean circulation has been estimated from 1993 to 2000 with the high resolution ocean circulation model described above, assimilating satellite altimetry (TOPEX/POSEIDON), climatological temperature and salinity, and surface flux estimates from operational weather re-analyses of the National Centers for Environmental Prediction (NCEP). The assimilation improves the accuracy of the ocean circulation estimate as illustrated in Figure 1, which compares model estimates with independent in situ measurements. The advanced assimilation schemes (adjoint and KFS) provide physically consistent estimates of the ocean's temporal evolution, allowing quantitative diagnosis to be made of processes underlying observed changes. For example, Figure 2 describes the heat balance across the tropical oceans around the globe (average within 20º of the equator.)

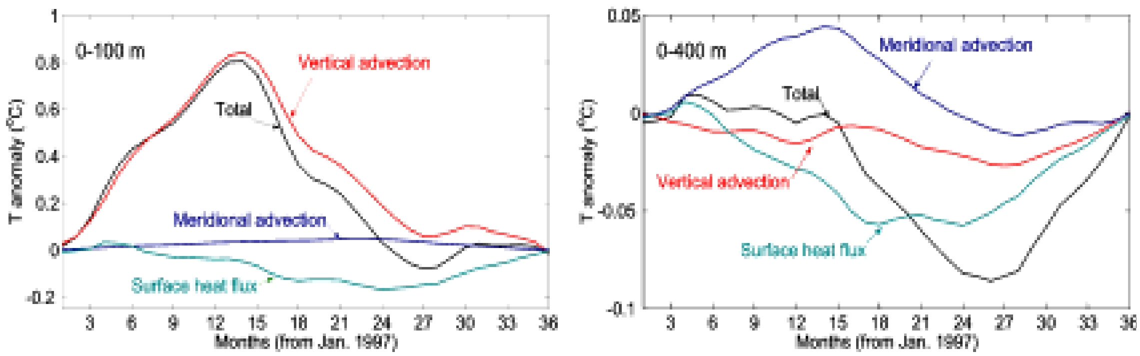

Figure 2: Global Heat Balance within 20º of the Equator. [Anomalies are driven by vertical advection near the surface (left) and by meridional advection over deeper layers (right).]

The effects and control of the Indonesian Throughflow (ITF) have been investigated by the forward model and its adjoint (Lee et al., 2001a, b). The Indonesian Throughflow (the exchange between the Pacific and Indian Oceans through the Indonesian Archipelago) is an integral element of the global meridional circulation ("global conveyer belt") that also plays a significant role in modulating El Nino/La Nina. Figure 3 illustrates the effect of blocking the ITF on sea surface temperature (SST) which has an important consequence on air-sea heat exchange. Blockage of the ITF depresses the mean thermocline of the tropical Pacific and raises it in the Indian Ocean. Blocking the ITF also reduces seasonal-to-interannual thermocline fluctuations in the equatorial Pacific because the resulting deeper thermocline attenuates fluctuations forced by local Ekman pumping. The ITF also affects the thermocline properties in the equatorial Pacific by regulating the tropical-subtropical exchange rate.

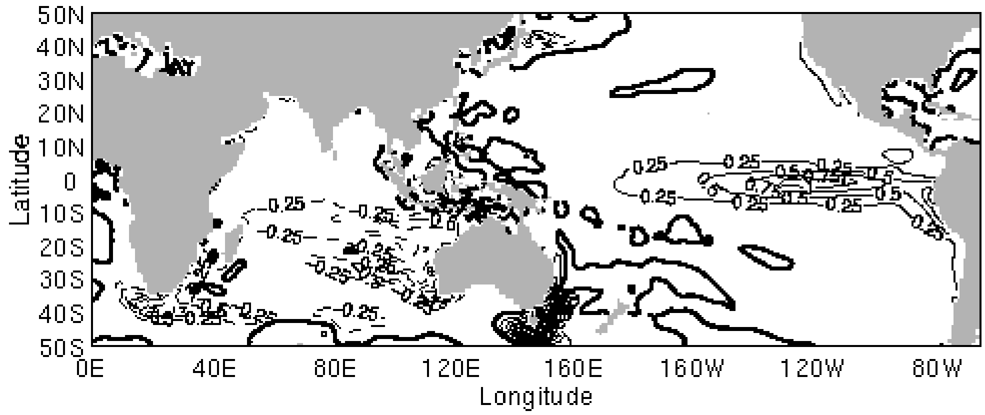

Figure 3: Changes in Time-mean SST with Closed Indonesian Passages. [Blockage of the ITF raises (lowers) SST in the central and eastern equatorial Pacific (southern Indian Ocean).]

Besides being an effective tool for data assimilation, the adjoint model provides an efficient means to evaluate model sensitivity to various controls. For instance, Figure 4 illustrates the sensitivity of the annual mean ITF transport to the annual mean zonal wind stress derived from a single integration of the model adjoint (Lee et al., 2001b). The remote effects of wind forcing shed light on planetary wave dynamics and vorticity balance. In particular, integration of these results with surface wind estimates elucidate driving mechanisms of ITF variability and provide insight into effects of air-sea interaction. For instance, such analysis suggests that observed anomalously strong ITF transport in 1988 was due to anomalous easterly winds over the equatorial Pacific. Effects of winds over the Indian Ocean are found to counteract contributions by Pacific winds, which can be attributed to the Walker circulation.

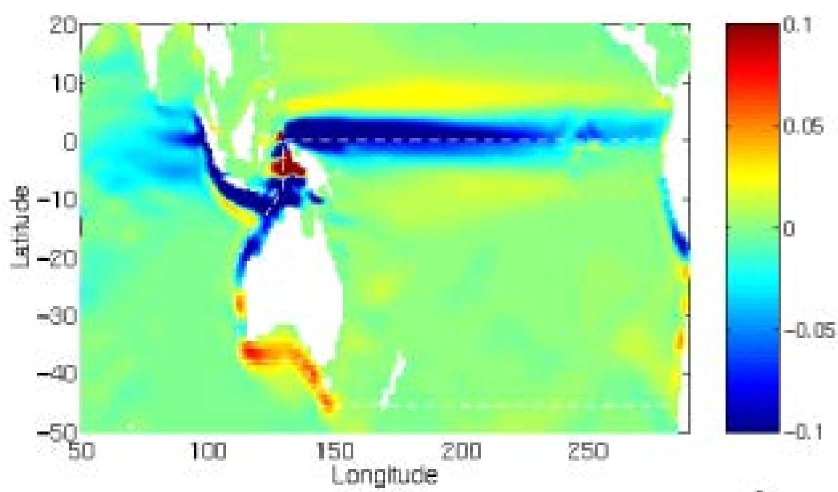

Figure 4: Sensitivity of ITF Transport to Zonal Wind. [ITF transport is sensitive to winds in the equatorial Pacific and the eastern seaboard of the Indian Ocean.]

IMPACT/APPLICATIONS

Data assimilation's regular and complete description of the ocean facilitates a wide range of studies in ocean circulation and its applications. This is because it is difficult to make inferences about the ocean continuum from individual measurements without knowledge of the surroundings. Processes controlling the state of the ocean and its evolution can be diagnosed and monitored to help detect and anticipate climate variabilities. Descriptions of ocean circulation also help understand and quantify the carbon cycle and other biogeochemical processes of the ocean that are affected by advection and mixing (see "TRANSITIONS" below.) Data assimilation contributes to practical applications of oceanography that require complete descriptions of the time evolving flow field and thermal structure such as fishing, shipping, search and rescue, industrial and naval operations, and weather forecasting. Model-data syntheses also help identify sources of model inaccuracies, providing an objective basis for ocean model improvement. Additionally, data assimilation helps in the design of optimal observing systems by quantifying impacts of different observing strategies on the accuracy of the syntheses.

Finally, the assimilation system itself (adjoint and PKFS) provides a versatile tool for other applications. The assimilation system can be employed to assimilate other data types and/or applied to other configurations including regional and biogeochemical studies. The MIT general circulation model can also be converted to an atmosphere model, and thus provide a system for atmospheric and/or coupled ocean-atmosphere data assimilations. Application of the model adjoint to sensitivity studies is an emerging area of investigation that provides new insight into the workings of complex systems.

TRANSITIONS

The ocean circulation estimates resulting from this project are being utilized by several external investigators in various applications. These include investigation of the uptake and transport of biogeochemical tracers (carbon, oxygen, nitrogen, and nutrients) (M. Follows, MIT), carbon-cycle modeling (N. Gruber, UCLA; C. LeQuere, MPI, Germany), and studies in the effects of ocean circulation on earth rotation (R. Gross, JPL).

Within the ECCO consortium (see "RELATED PROJECTS"), this effort has helped early development of the parallel MIT ocean circulation model and has spearheaded the creation and application of its adjoint. Experience gained from exploring the synergism between the adjoint and KFS approaches will help advance the consortium's complementary investigations.

RELATED PROJECTS

This project is part of a larger consortium formed under the National Oceanographic Partnership Program (NOPP). The consortium, entitled "Estimating the Circulation and Climate of the Ocean" (ECCO; http://www.ecco-group.org/) consists of groups at the Scripps Institution of Oceanography (SIO; D. Stammer, PI), Massachusetts Institute of Technology (MIT; J. Marshall, PI), and the present effort at JPL. The MIT group is the lead in forward model development, while SIO and JPL are leads in data assimilation. Assimilation efforts at SIO and JPL are closely linked and synergistic. The focus of the SIO group is on optimal assimilation utilizing a comprehensive set of observations whereas the JPL group is focusing on high resolution near real-time analyses. The trade-off between optimality and scope is justified given present limitations in computational resources. The two approaches will merge as knowledge and experience is gained by the complementary studies and as additional computational resources become available.

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